D1

COLLEGE OF AGRICULTURE UNIVERSITY OF NEBRASKA
AGRICULTURAL EXPERIMENT STATION
RESEARCH BULLETIN 26

Effect of Environment on Potato Degeneration Diseases

R. W. GOSS
DEPARTMENT OF PLANT PATHOLOGY

LINCOLN, NEBRASKA
MARCH, 1924

COLLEGE OF AGRICULTURE UNIVERSITY OF NEBRASKA
AGRICULTURAL EXPERIMENT STATION
RESEARCH BULLETIN 26

Effect of Environment on Potato Degeneration Diseases

R. W. GOSS

DEPARTMENT OF PLANT PATHOLOGY

LINCOLN, NEBRASKA
MARCH, 1924

CONTENTS

Introduction 5

Consideration of the Problem 5

Experimental Data 10

Greenhouse Experiments 10

Field Experiments 15

Field Experiments with Miscellaneous Mosaic 27

Correlation of Experimental Results with Mosaic Incidence in Commercial Fields 31

Discussion 37

Literature Cited 40

SUMMARY

1. The symptoms of potato mosaic in the Bliss Triumph variety are influenced to a great degree by environmental conditions.

2. Temperatures above 70° F. tend to decrease the number and severity of the symptoms, while temperatures below that point increase their visibility.

3. Mottling was found to be the most constant symptom when temperature alone was varied. High temperature with intense sunlight caused the disappearance of this symptom.

4. Wrinkling, curling, and rugosity were eliminated at the higher temperatures on mild mosaic plants.

5. High temperature is a greater factor in masking mosaic symptoms than low moisture or increased sunlight, altho under field conditions all 3 usually occur together.

6. The symptoms of mild mosaic reacted more quickly to environmental factors than the more severe types and the combinations of mosaic and spindle-tuber used in these experiments.

7. The effect of the environment on the symptoms decreased with the increasing age of the plant.

8. Under field conditions mosaic was more severe with early planting while spindle-tuber was more severe in the late plantings.

9. Short periods of 4 to 8 days of high temperature and increased sunlight were found sufficient to eliminate the leaf symptoms of mild mosaic and to decrease those of the more severe types.

10. The symptoms of mild mosaic under certain conditions appeared more serious than the symptoms of the more severe types of mosaic appeared under other conditions that were less favorable for the manifestations of the symptoms.

11. Climatic conditions as noted above can be correlated in commercial fields with:

(a) Changes in the appearance of the symptoms on the plants during the same season.

(b) Changes in the amount of visible mosaic in the same region for different seasons.

(c) Changes in the amount of mosaic found in northern grown seed from Nebraska when planted in the southern states.

12. In view of the data presented in this paper, the author believes that the effect of high temperature, intense sunlight, and low moisture in masking the symptoms of mosaic in western Nebraska is of as great importance as aphid transmission of the disease.

13. In order to select healthy seed, to determine the percentage of mosaic, or to rogue properly, the conditions under which the plants are growing must be considered, and the work done at the most favorable time rather than at any fixed date.

Effect of Environment on Potato Degeneration Diseases

R. W. GOSS
DEPARTMENT OF PLANT PATHOLOGY

INTRODUCTION

During recent years much of the investigational work on the degeneration diseases of the potato has been directed toward the separation and identification of a number of diseases formerly grouped under the general names of mosaic, leaf roll, and "running out". Extensive studies have also been made on methods of transmission, host range, overwintering and the identification of the evasive causal factor.

Investigations of this type, however, have progressed slowly because of the necessity of developing new methods of research, because of the complexity of the problem, and because of the lack of knowledge regarding the causal factors. Meanwhile there is an immediate and pressing demand from the seed growers and the inspectors of certified seed for advice and instruction regarding these diseases. Their chief interest is in the problems of (1) the recognition of these diseases in the field, (2) their effects upon yield rate, and (3) methods of control. It seems, therefore, desirable to present here the results of certain preliminary studies which contribute in some measure to a better understanding of these more practical problems and to point out some of the factors, and their effects, which must be considered in a study of these problems.

CONSIDERATION OF THE PROBLEM

In discussing the 3 problems outlined above, emphasis will be laid upon the first, *i. e.*, the recognition of these diseases in the field. This is prerequisite to a proper investigation of the other 2 problems.

The symptoms of mosaic and related diseases have been known in a general way for a number of years. The recent publications on the subject, however, have caused a temporary confusion in the minds of workers not specializing on these diseases, but it is hoped they will eventually lead to a clearer understanding of the problem. The confusion, however, is nevertheless present. Quanjer (1921) (1923) describes from 6 to 8 different degeneration diseases occurring in Europe, Murphy (1921-B) lists 6 diseases of this type, and Schultz and Folsom (1923,

p. 61) distinguish 7 diseases occurring on the Green Mountain variety. They also note that combinations of these diseases may occur, thus increasing the complexity of the problem. When we consider that these authors were working with different varieties, under different conditions, and often used different terms to describe similar symptoms, the reason for the resultant confusion is obvious. Schultz and Folsom (1923) give a very clear definition of the symptoms used in their descriptions. This should result in materially increased clarity of description in American papers. Their terminology will be used thruout this paper.

Schultz and Folsom (1920) (1923) demonstrated the possibility both of intervarietal transmission of certain degeneration diseases and of varietal modification of symptoms. However, the problem of varietal manifestations of these diseases is still largely unsolved.

The other factor to be considered, that of the effect of environment on the disease symptoms, has already received considerable attention. The masking of symptoms has been observed by numerous workers. Most of the statements in the literature, however, regarding this phenomenon have been based on general observations; and often where experimental evidence is presented, detailed data regarding the environmental factors are lacking.

The only experimental evidence secured under controlled conditions with which the author is acquainted was presented by Johnson (1922). He found the optimum temperature for the appearance of the symptoms to be between 14° and 18° C. "Above 20° C. symptoms disappear, the rate of recovery from the disease being increased in proportion to increase of temperature within the limits of host development. To completely inhibit the disease, however, within a period of one to two weeks, a temperature of 24° to 25° C. is necessary; and this may be regarded as the maximum temperature for mosaic manifestation in the potato. New leaves, free from symptoms, appear quickly at this temperature, and older leaves gradually lose their symptoms, the rate of 'recovery' being roughly proportional to the age of the leaf." He does not state the type of mosaic or the severity of the symptoms on the plants with which he was working, or the variety of potatoes used, nor does he mention soil moisture or sunlight, altho it is to be assumed that they were kept similar in the parallel tests.

Schultz, *et al.* (1919, p. 250) report that parallel plantings in Maine and Colorado showed an absence of mottling in Colorado and distinct mottling in Maine. Plantings in Maine and at

Washington, D. C., gave somewhat similar results. Plantings made for 3 successive seasons in northeastern and southwestern Maine showed mottling to be inhibited in southwestern Maine, and the return of the progeny to northeastern Maine resulted in the reappearance of mottling. No data are given concerning the environmental factors of these different localities or the type of mosaic being studied. Schultz and Folsom (1923, p. 99-102) report a number of experiments in which the symptoms of these diseases were affected by climatic conditions. They found that mottling was particularly masked on mild mosaic plants when grown in Virginia in comparison with Maine and Long Island plantings. In greenhouse experiments they found wrinkling and mottling to be more marked at 16° than at 24° C. and that the transference of the plants from the high to the low temperature increased the symptoms on the new foliage. They found mottling to be more distinct on caged than on uncaged plants in the field. In other experiments with various types of mosaic, they report that a reduction in sunlight decreased the apparent dwarfing and increased mottling. In fertilizer experiments they found a decrease in the percentage of mosaic and in the distinctness of mottling, during the first part of the season, by high nitrogen and potash fertilizers. In none of this work, except in the greenhouse experiments, do the authors present very detailed information regarding temperature, moisture, and sunlight (aside from shading in insect cages) occurring in their experiments. They do not report, with the exception of the one experiment in Colorado, a change from distinct mottling to an absence of mottling. They find that a difference in climatic conditions results chiefly in a difference in the distinctness of the mottling, but that the stage or type of mosaic remains the same.

Ducomet (1923) in a recent paper discusses the influence of environment on the symptoms. He lays great stress upon moisture as well as temperature, and correlates the appearance of mosaic with wet seasons or with local wet regions in dry seasons. From his greenhouse experiments conducted at 12°-15° and 17°-22° C., some of the plants being under cloth, he concludes that "basses temperatures et air sec favorisent les deformations; temperatures élevées et air humide favorisent la maculature." It is to be noted, however, that his high temperatures were not as high as the temperatures employed by Johnson (1922), nor as high as the temperatures often occurring in the field in Nebraska. He found the disease to be more evident under cloth. He does not give any detailed data on temperature or moisture in his field observations.

Murphy (1921) observes that, "a high temperature and favorable conditions for quick growth early in the season reduce the symptoms of mosaic." He notes that a mean temperature of 71.1° F. during June at Ottawa resulted in the suppression of the symptoms of mosaic, while in the previous year, with a mean temperature of 61.8° F., the disease was severe. He shows that the symptoms of the disease were masked under certain conditions, but that the plants remained a source of infection for neighboring healthy plants. The symptoms reappeared when tubers from these plants were grown the following year under more favorable conditions for the appearance of the disease. He finds that early planting favors the appearance of mosaic. The same author (1923) considers that moisture as well as temperature may influence the appearance of the disease.

In considering the second question, *i. e.*, the effect of these diseases on yield, no attempt will be made to review all the literature. Numerous investigators have reported variable decreases in yield as being due to these diseases. A few points in relation to this phase should be considered here, however.

The effect of locality on yield rate in relation to these diseases is of considerable importance. Schultz and Folsom (1923) report that an all-mosaic condition reduced the yield rate of Green Mountains more on Long Island than in northeastern Maine. Murphy (1921) reports that plants in which the symptoms of mosaic were masked gave practically as good yields as neighboring healthy plants. Data presented by Edgerton and Tiebout (1921) and other unpublished data obtained on Nebraska grown seed in Louisiana, show a much greater decrease in yield, due apparently to mosaic, in the South than in Nebraska. It has been noticeable, however, in many of the yield tests that there is a considerable variation in the amount of mosaic present in different strains of potatoes giving about the same yields and *vice versa*. An example of this is shown by Edgerton and Tiebout (1921, p. 11). Their data show that Lots Nos. 2 and 3 have practically the same yield, but differ in the amount of mosaic by about 30 per cent. Again, Lot No. 10 outyields Lot No. 5 by about 55 bushels, altho the amount of mosaic is the same in both cases. This can be accounted for by the possibility that different types of mosaic were present, together with the fact that different types of mosaic affect the yield rate differently. Very little evidence has been published on this point, and more information is needed to determine the tolerance of different types of these diseases to be allowed in our seed potatoes for different localities.

Regarding the control of these diseases, a great number of factors must be taken into consideration, but do not properly belong in this paper, except for certain phases of the problem in relation to environment. The general methods of control usually advised have comprised roguing, selection of healthy hills, seed plats, and isolation. Schultz and Folsom (1921, p. 75) have noted a regional variation in the amount and spread of mosaic in experimental fields, apparently due to the effect of climate on the amount of aphid infestation. Quanjer (1921, p. 143) found a difference in the spread of leaf roll and related diseases when parts of split tubers were planted in different localities. He found more green flies present in localities where the disease spread the most, but apparently does not think this is the sole explanation. Murphy (1921) has also noted regional differences in the spread of mosaic.

Thus the effect of environment is of considerable importance in determining the degree of isolation necessary in seed plats. The amount of infestation is important as regards the time of roguing or of hill selection. The direct effect of masking on the ability to distinguish and remove diseased plants is obvious.

Another factor in relation to control is the possible transmission of the disease from native plants, and this again will vary in different localities.

This short review of the literature must lead one to the conclusion that environment exerts a marked influence upon the symptoms, the spread, and the effect on yield of these diseases. The exact conditions causing the masking of symptoms and the degree of masking, still remain to be demonstrated for the various types of mosaic in different varieties, and practically no information is given regarding the effect of such factors on the spindle-tuber disease. Until the effect of these external factors on the appearance, spread and yield is determined for the different varieties and for the different diseases, it is manifestly impossible to come to a clear understanding of these diseases in the various potato growing sections and to combat them intelligently. The problem still remains in many ways purely a local one.

Conditions in Nebraska and other dry land sections of the West are markedly different from those prevailing in the East, where most of the experimental work in the United States on these diseases has been performed. It has long been evident that experimental results from eastern states cannot be applied, *in toto*, to the potato sections of the West. Conditions of temperature, moisture, sunlight, aphid infestations (usually very scarce),

and possible native hosts other than the potato are very different from those occurring in the East. The varieties being grown are not those upon which most of the reported experiments have been conducted. The appearance of these diseases and even the severity of the different types in their effect on yield are very diverse. Increases in mosaic in the absence of great numbers of aphids are common. The necessity for further work on this problem in various parts of the country, but particularly in the West, even at the risk of considerable duplication, cannot be too greatly emphasized.

EXPERIMENTAL DATA

GREENHOUSE EXPERIMENTS

EFFECT OF TEMPERATURE ON THE SYMPTOMS DECEMBER 22, 1922, TO APRIL 16, 1923

The following experiment was planned to determine the effect of temperature on the symptoms of certain degeneration diseases in the Bliss Triumph variety.

Source of Seed.—The seed used in this and the following experiments, except where otherwise noted, was obtained from Dr. Donald Folsom, Maine Agricultural Experiment Station, August 20, 1922, and was designated by him as follows: mild mosaic, medium plus mosaic, spindle-tuber, spindle-tuber+mild mosaic, and curly dwarf (spindle-tuber+leaf rolling mosaic).

In a recent publication, Schultz and Folsom (1923) state that their former designation of medium plus mosaic is in part a combination of rugose mosaic with spindle-tuber. The material sent to the author undoubtedly shows both mosaic and spindle-tuber characteristics on the vine and spindle-tuber symptoms on the tubers, but has not appeared as serious as the spindle-tuber+mild mosaic.

Methods.—One tuber from each of these 5 lots of seed was cut into 4 equal sized pieces and used for planting at 4 different temperatures. Thus all 4 plants listed in Table 1 under each disease were from the same mother tuber.

The plants were grown in 10,000 gms. of soil in galvanized iron containers in which the soil moisture was kept approximately constant by methods previously described by the author, Goss (1923). The soil was held at 22 per cent moisture (dry weight), this being equal to the soil moisture equivalent.[1] Immediately after planting, the containers were placed at the de-

[1]The author is indebted to Mr. J. C. Russel of the Agronomy Department, Nebraska College of Agriculture, for the determination of soil moisture equivalents.

sired temperature. The temperatures used were 15°, 20°, 25°, and 30° C. These temperatures were held constant for both air and soil in temperature cases described by Peltier (1923). On February 9, when the plants were half grown, they were transferred to different temperatures, the plants at 15° and 20° being removed to a greenhouse held at approximately 25°. The plants at 25° and 30° were transferred to temperature cases held at 15°.

The light conditions were approximately the same in all cases. The sunlight during the experiment was very weak, and as a result the plants were considerably etiolated.

Observations were made every week during the experiment, and after the temperatures were changed, observations were made separately on the old and new foliage. Healthy tubers were grown in each set as controls, and in every instance remained healthy except for chlorosis and leaf dropping at the high temperatures, so that these symptoms were not recorded for the mosaic plants. The extent of dwarfing was determined by comparing the infected plants with the controls in the same sets.

Results.—A summary of the symptoms appearing on the individual plants is given in Table 1. The results show a rather uniform and marked gradation in the absence or in the severity of the symptoms of the various plants growing at different temperatures. More symptoms were present and they were all more distinct at 15° than at 20° C. At 25° the mild mosaic plant appeared healthy while at 30° many of the symptoms on all plants were absent. When plants growing at 15° were transferred to 25°, the symptoms usually persisted in a milder form on the old leaves, while in most instances the new leaves appeared healthy. The symptoms persisted longer on these plants than on the plants transferred from 20° to 25°. The reverse was true on plants grown at 25° and 30° and transferred to 15°. Here the old leaves sometimes developed symptoms under the more favorable temperature conditions while in most instances the new leaves showed very distinct symptoms. These were never as distinct on the plants previously grown at 30° as on those grown at 25°, and in most instances they were not as distinct even on the new leaves at 15° as they were on plants started at 15°. Evidently the high temperatures not only masked the symptoms, but inhibited the development of the symptoms when the plants were changed to a lower temperature.

Contrary to expectations, under the conditions of this experiment, mottling of the leaf was the most persistent symptom present; this was possibly favored by the weak sunlight conditions.

TABLE 1.—*Effect of temperature upon the symptoms of certain degeneration diseases appearing on the foliage developed during the period of growth, (I) before and (II) after the change of temperature*[1]

Planted December 22—Temperature changed February 9, plants dug April 16

Plant No.	Period of growth	Temp. °C.	Foliage formed before or after temperature change	Symptoms: Dwarfing	Mottling	Wrinkling	Rugosity	Ruffling	Curling	Miscellaneous notes
			MILD MOSAIC							
1	I	15	Before		±	—	±	±	±	
	II	25	Before		—	0	—	—	—	
			After		0	0	0	0	0	
2	I	20	Before		±			±		
	II	25	Before		—			—		
			After		0			0		
3	I	25	Before		0	0	0	0	0	
	II	15	Before		—	0	0	0	0	
			After		±	—	±	±	±	
4	I	30	Before		0	0	0	0	0	
	II	15	Before		0	0	0	0	0	
			After		—	—	—	—	—	
			MEDIUM + MOSAIC							
1	I	15	Before		+	+	+	+	+	Tubers S. T.[2] —
	II	25	Before		±	—	±	±	—	
			After		—	0	0	0	0	
2	I	20	Before		±	±	±	±		Tubers S. T.—
	II	25	Before		—	0	—	—		
			After		—	0	0	0		
3	I	25	Before		—		0	0	0	Tubers S. T. +
	II	15	Before		±		0	0	0	
			After		+		+	+	+	
4	I	30	Before		—			—		Tubers S. T. —
	II	15	Before		—			—		
			After		—			—		
			SPINDLE-TUBER							
1	I	15	Before	—				—		Uprightness
	II	25	Before	—				—		Tubers S. T. +
			After	—				—		
2	I	20	Before	—						Uprightness
	II	25	Before	—				—		Tubers S. T. +
			After	—				0		
3	I	25	Before	—				—		Uprightness
	II	15	Before	—				—		Tubers S. T. ±
			After	—				—		
4	I	30	Before	—				0		Uprightness
	II	15	Before	—				—		Tubers S. T. ±
			After	—				—		

TABLE 1.—CONCLUDED.—*Effect of temperature upon the symptoms of certain degeneration diseases appearing on the foliage developed during the period of growth, (I) before and (II) after the change of temperature*[1]

Planted December 22—Temperature changed February 9, plants dug April 16

Plant No.	Period of growth	Temp. °C.	Foliage formed before or after temperature change	Symptoms: Dwarfing	Mottling	Wrinkling	Rugosity	Ruffling	Curling	Miscellaneous notes
SPINDLE-TUBER + MILD MOSAIC										
1	I	15	Before	±	+	±	+	+	+	Uprightness
	II	25	Before	±	±	—	±	±	±	Tubers S. T. +
			After	±	—	0	0	—	0	
2	I	20	Before	±	+			+		Uprightness
	II	25	Before	±	—			—		Brittleness
			After	±	0			0		Tubers S. T. ±
3	I	25	Before	±	—		0	—	0	Uprightness
	II	15	Before	±	—		0	—	0	Brittleness
			After	±	+		±	+	±	Tubers S. T. +
4	I	30	Before	—	—			—		
	II	15	Before	—	—			—		Tubers S. T. +
			After	—	—			—		
CURLY DWARF										
1	I	15	Before	+	+	+	+	+	+	Slight rolling
	II	25	Before	+	+	±	+	+	+	Uprightness
			After	+	±	0	+	+	+	Brittleness
2	I	20	Before	+	±	±	—	—	±	Uprightness
	II	25	Before	+	±	—	—	—	±	Tubers S. T. +
			After	+		0				
3	I	25	Before	+	—	0	0	0	0	Slight rolling
	II	15	Before	+	+	—	±	±	+	Uprightness
			After	+	+	—	+	+	+	Tubers S. T. ±
4	I	30	Before	+	0		0	0	0	Slight rolling
	II	15	Before	+	±		0	±	0	Uprightness
			After	+	±		±	±	±	Tubers S. T. ±

[1] The symbols designate the severity of the symptoms, i. e., + = very distinct, ± = moderately distinct, — = slight, 0 = absent.

The absence of any symbol indicates that the symptom did not appear at any time during the experiment.

[2] The abbreviation S. T. under miscellaneous refers to the spindle-tuber symptoms on the new tubers.

Wrinkling was probably the least permanent symptom. When plants were transferred to higher temperatures, one of the first changes was the decrease and usually the elimination of wrinkling. Curling and rugosity reacted similarly, both being less persistent than ruffling and more persistent than wrinkling.

The symptoms of spindle-tuber were apparently less influenced by temperature than those of mosaic. The erectness, spindleness, and slight dwarfing of the vine along with the ruffling of the leaves and the tuber symptoms, remained fairly constant at all temperatures.

The results presented here show that a temperature somewhere between 20° and 25° is the critical point in determining the presence or absence of mosaic symptoms. As the temperature is increased the symptoms tend to disappear, while the reverse is true of lower temperatures. The data presented here agree in general with those of Johnson (1922).

One important fact that will be noted later in connection with field observations was the apparent greater severity of mild mosaic under certain conditions, for example at 15°, than a more severe type, such as medium plus mosaic or curly dwarf, growing under a different set of conditions, for example at 30° C.

It must be remembered that in this experiment only one environmental factor was varied and that variation in other factors would probably cause a change in the apparent temperature effect on symptoms.

It is true that the seed used in this experiment may have been infected with other diseases the previous year, as they had been grown in the field subject to infection. However, this experiment was not conducted in any attempt to prove or disprove the previous diagnosis of the disease and the fact that the plants of each disease type at each temperature were grown from the same tuber eliminated to a great extent all factors other than the one under consideration, *i. e.*, temperature.

It is evident from this one experiment, and from other tests made showing the same results, that the symptoms of these diseases may vary so greatly under different conditions that it would be an impossible task to attempt to classify such diseases in commercial fields. While it may be held that this experiment was conducted under different conditions from those occurring in the field, it will be shown later that such results can be obtained under field conditions.

EFFECT OF SUNLIGHT ON THE SYMPTOMS
FEBR. 19, 1923, TO MAY 25, 1923

Using mild mosaic, medium plus mosaic, and curly dwarf seed tubers from the same source as in the previous experiment, a preliminary test was made of the effect of shading on mosaic symptoms. Tubers from these 3 lots were halved and one-half grown in direct sunlight while the other half was grown under

2 thicknesses of cheesecloth. Healthy tubers were planted and grown under the same conditions. The air temperature was kept at approximately 18° C. and the soil was kept at a rather high soil moisture content.

The mottling of the foliage was in every instance more distinct under shade than in the sunlight altho it was present on all plants. Rolling, streaking, and burning were present on the medium plus mosaic and curly dwarf plants in the sunlight and absent under shade. The streaking occurred only on the stems and petioles. Wrinkling, ruffling, rugosity, brittleness and curling varied considerably during the experiment both in sunlight and shade and no clear cut difference was noted under the 2 conditions. Rolling, uprightness, rigidity, streaking, and dwarfing were present in medium plus mosaic and curly dwarf plants and absent in mild mosaic plants. In all instances the symptoms were more severe in curly dwarf plants.

While the number of plants was small, a clear cut difference was present in regard to mottling and rolling.

More extensive and carefully controlled experiments may show differences in the appearance of other symptoms not evident in this preliminary test.

There was a distinct difference in what might be termed the severity of the disease, with the 3 types used under both conditions.

FIELD EXPERIMENTS

In 1923 experiments were conducted in an effort to determine the effect of environmental conditions on the symptoms of these diseases in the field.

Methods.—Experimental plots were located in various sections of western Nebraska. The potatoes were grown under different conditions and with different dates of planting as follows:

Plot A—Planted May 15—Scotts Bluff Substation, Mitchell, Nebraska.

Plot B—Planted May 15—Scotts Bluff Substation, Mitchell, Nebraska, irrigated.

Plot C—Planted June 1—Scotts Bluff Substation, Mitchell, Nebraska, irrigated.

Plot D—Planted June 1—August Gadeken's farm, Bushnell, Nebraska.

Plot E—Planted May 10—Muldoon farm, Dawes table, Chadron, Nebraska.

Plot F—Planted June 1—Muldoon farm, Dawes table, Chadron, Nebraska.

Plot G—Planted June 20— Muldoon farm, Dawes table, Chadron, Nebraska.

In each of these plots potatoes were planted from the same source and with the same diseases as those listed on page 10. The seed used was cut into pieces averaging about 30 gms. in weight. When possible, the different pieces from the same tuber were planted in different plots in sequence. In other cases,

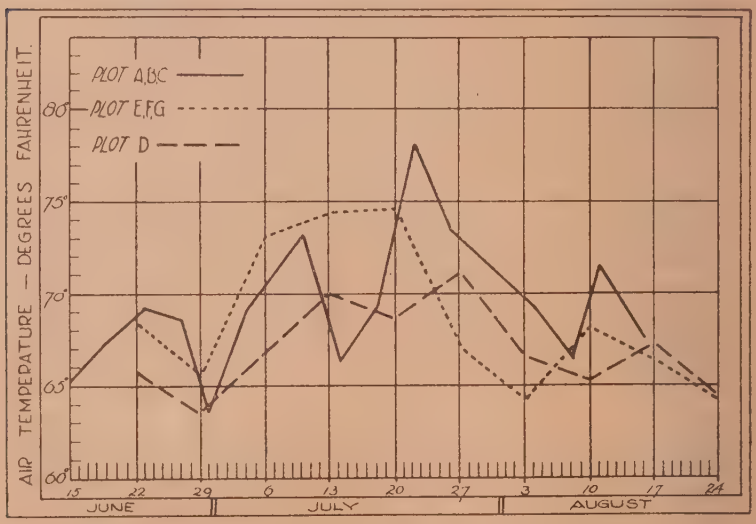

FIG. 1.—Graph showing air temperatures for all 1923 Experimental Plots.
Plots E, F, G, and D represented by mean weekly temperatures.
Plots A. B. and C represented by the mean temperatures for the periods between the mosiac readings as listed in Tables 2-7.
All mean temperatures obtained from 2-hour readings, i.e., 12 readings every 24 hours instead of using maximum and minimum temperatures.

tubers from the same hill were used similarly. Air temperature records were kept at each plot (figure 1) and soil moistures were also determined weekly in the plots located at Mitchell. Rainfall and sunshine records were obtained from the U. S. Weather Bureau records made at the Substation. In Plots A and B, notes were taken on the date of emergence, and the mosaic readings were made at least once a week until the middle of August, partly by the author and partly by Mr. William Morrow, Field Assistant. In the other plots, readings were

made 3 times during the season by the author. At digging time, all hills were dug, weighed and graded separately.

Results.—No attempt will be made here to take up the records of the symptoms occurring on the individual plants of each plot, but some specific examples of the effect of external conditions on the appearance of the symptoms will be shown. In general it can be said that the differences in symptoms between the different plots were no greater than the differences observed during the season in any one plot. As an example,

TABLE 2.—*Symptoms appearing on mild mosaic plants. Plot 1 (8 plants)*[1]

Date	Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf dropping
June 15			2		1	1									
June 19			1	1		1									
June 23				1		1		1							
June 27				1											
June 30									1	1	1				
July 4															
July 10															
July 14			3	2	1	2	2								
July 18				1		1									
July 22				1	2	1									
July 26			3	1	2	2	1	1							
Aug. 4			5	3	3	3	1	2							
Aug. 8			4	2	2	2	1	2							
Aug. 11			4	2	2	3	1	3							
Aug. 16			1	3	2	3	2	2							

[1]The symbols used in Tables 2–5, 7 and 8 refer to the degree of severity of each symptom as represented by figures 1 to 5, the extremes being: 1—"very slight" and 5—"very severe." These were the average symptoms on all plants. Usually the symptoms were identical or nearly so in all plants of each disease. The omission of any symbol indicates that the symptom did not appear.

the changes will be shown in detail only for Plot A. In examining the following tables, it is well to keep in mind the temperature curves shown in figure 1.

The most marked differences occurred, as in the greenhouse experiment, with the mild mosaic plants. It will be seen from Table 2 that the symptoms during the early season were not very reliable, but as the season progressed they became more fixed. Comparing Table 2 with the temperature curve shown in figure 1 for Plot A, it will be seen that from June 30 to July 10 the temperature rose rapidly, and this corresponds with the disappearance of the few symptoms previously present. A sharp drop in temperature after the 10th accompanied by 0.8 inch of rain and a decrease in sunshine resulted in the reappearance of the symptoms in a more serious form. This was followed by another sharp rise in temperature resulting in the disappearance of mottling and a smoothing out of the previously wrinkled leaves. It is evident that with the increased age of the plant the effect of temperature on such symptoms as wrinkling and rugosity is not as marked as on the younger plant. Another drop in temperature accompanied by rainfall resulted in the second reappearance of mottling as well as other leaf symptoms, which continued to be very evident thruout the remainder of the season during which records were obtainable. While the mottling showed greater changes than appeared in the greenhouse experiment, the author believes this to have been due to the fact that the intense sunlight occurring during these periods of high temperature was great enough to cause these changes, while in the greenhouse, as already noted, the sunlight was weak. At the altitude of this experiment, about 4,000 ft. as in many other regions of the West, the sunlight is intense enough during the middle of the day to cause the leaves to droop and become flaccid.

In Table 3 are shown the symptoms for the plants listed as "medium plus mosaic", also in Plot A. We find the same general changes as shown in Table 2. The mottling was not as evident on these plants as on those listed as mild mosaic. However, this mottling and also curling showed the greatest effects of temperature changes, altho the severity of all other leaf symptoms was also decreased during the same periods. The addition of uprightness and rigidity to the list of symptoms as well as the increase in ruffling was probably due to the spindle-tuber apparently present in this combination called medium plus mosaic. Other symptoms, as rugosity and curling, were greater than in mild mosaic. The same general relation to the effect of temperature is evident.

TABLE 3.—*Symptoms appearing on medium plus mosaic plants. Plot A (5 plants)*[1]

Date	Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf dropping
June 15				1	1	1									
June 19				1	1	2	1								
June 23				1	1	1									
June 27				1	1	1									
June 30			1	1	1	1		2	1	1					
July 4				1	1	1	2	2	1						
July 10				1	1	2		3	1	1					
July 14			2	2	2	4	2	5							
July 18				1	2	2		1	1						
July 22				1	2	2	2	2	1						
July 26			1	2	3	3	3	2	1						
Aug. 4			2	3	3	3	3	4	1						
Aug. 8			1	3	3	4	2	3							
Aug. 11			1	3	3	4	2	3							
Aug. 16			1	4	3	4	2	3							

[1]For explanation of symbols see Table 2.

In Table 4 are listed the symptoms of plants affected with spindle-tuber+mild mosaic. These plants appeared more seriously diseased than the medium plus mosaic plants. The uprightness and rigidity of the plants were more marked, and dwarfing occurred that was not evident in the other plants listed in Tables 2 and 3. A decrease in the germinating power of such seed was also evident.

Here again the same general effect of temperature on the symptoms was noticeable. Mottling was the least permanent symptom. The other leaf characters showed very slight changes

TABLE 4.—*Symptoms appearing on spindle-tuber+mild mosaic plants. Plot A (4 plants)*[1] [2]

Date	Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf dropping
June 15	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...
June 19	...	...	...	1	...	...	...	...	...	1	...	...	...	...	...
June 23	...	...	...	1	...	...	...	...	...	2	...	...	...	...	...
June 27	...	...	1	1	...	...	...	...	...	2	...	...	...	...	...
June 30	...	...	...	2	...	...	...	...	1	2	...	...	...	...	...
July 4	1	...	...	2	2	2	...	2	1	1	...	...	...	...	...
July 10	2	...	...	...	3	2	1	4	2	...	...	...	...	...	...
July 14	1	...	1	2	4	3	3	2	2	...	...	...	...	...	...
July 18	1	...	...	2	3	3	2	3	3	...	...	...	...	...	...
July 22	1	...	1	2	3	2	3	3	1	...	...	...	...	...	...
July 26	...	...	5	4	2	4	5	3	4	...	...	...	...	...	...
Aug. 4	...	...	5	3	2	3	3	3	5	...	...	...	...	...	...
Aug. 8	...	1	5	2	1	2	3	2	2	...	...	...	...	...	...
Aug. 11	...	1	5	2	2	2	2	2	2	...	...	...	...	...	...
Aug. 16	...	1	4	2	2	2	2	3	2	...	...	...	...	...	...

[1] For explanation of symbols see Table 2.
[2] Three seed pieces failed to germinate. Average germination 8 days later than mild mosaic plants.

that could be correlated with temperature, indicating that the more serious the manifestation of disease, the less will be the effect of external factors.

Table 5 shows the symptoms of curly dwarf plants listed in the same manner. The effects of changes in temperature as noted for the other disease types were here hardly discernible. The greatest change noticeable in the field was in regard to rigidity and brittleness which decreased during the hot, dry periods. It is true, however, that if the numerical symbols representing the severity of the symptoms be added for the

TABLE 5.—*Symptoms appearing on curly dwarf plants. Plot A (4 plants)*[1]

Date	Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf dropping
June 15	1														
June 19	1			2											
June 23	2		1	2	1	2	1	1		1					
June 27	3		1	1	1	1				2					
June 30	3			1					2						
July 4	5			4	5	4	4	2	4	4					
July 10	5			3	4	5	2	3	3	1				1	1
July 14	5			3	5	5	4	4	2	1	1				
July 18	5			3	5	5	3	5	2						
July 22	5			4	3	4	4	3	4						
July 26	5			5	4	5	5	5	5		3				
Aug. 4	5			5	3	5	5	4	5	1	2				
Aug. 8	5	1		3	3	4	5	4	3	2			1	2	1
Aug. 11	5	2		5	3	5	5	4	4	2			1	5	
Aug. 16	Practically defoliated with early blight														

[1]For explanation of symbols see Table 2.

various dates it will be found that there was again a slight decrease during the period from July 14 to 22, with the greatest number occurring on July 26, thus corresponding with the other types. Differences were also noted in the field that were impossible to tabulate. It was clearly evident again that the more severe disease types react only slightly to temperature. The outstanding plant symptom here was the severe dwarfing occurring thruout the season. The addition of streaking and leaf dropping to the symptoms was apparently the result of the addition of "leafrolling mosaic" to spindle-tuber. These symptoms were more marked in the latter part of the season.

It is evident from this experiment that the differences observed on these plants during the season were so great that a reading for mosaic percentages or for disease types made during certain parts of the season would be subject to great error.

TABLE 6.—*Soil moisture expressed as per cent of moisture equivalent. Plots A, B, and C, 1923*

	June			July				August				September	
	10	19	26	3	10	18	25	2	9	18	25	5	8
Plot A	112	88	84	67	89	81	76	63	84	94	69	54	.....
Plot B	96	71	57	52	48	52	65	66	66	87	74	34	86
Plot C	105	77	84	84	80	70	74	59	70	100[1]	73	40	102[1]

[1]Irrigated.

TABLE 7.—*Symptoms on mild mosaic plants. Plot B (8 plants)*[1]

Date	Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf dropping
June 15	...	...	...	2	...	...	...	...	...	...	...	...	...	...	..
June 19	...	...	...	1	...	1	1	...	...	...	...	...	...	...	....
June 23	...	...	1	1	...	1	...	...	...	...	...	...	...	...	....
June 28	...	...	...	1	...	1	...	...	...	...	...	...	...	...	....
July 4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	....
July 10															
July 14			1	1		1									
July 18				1											
July 22															
Aug. 4	...	...	2	2	1	2	...	...	...	...	...	...	...	...	....
Aug. 8			4	2	1	2	1	1							
Aug. 11			5	2	2	3	1	2							
Aug. 15			5	3	2	4	1	2							

[1]For explanation of symbols see Table 2.

It is also seen that readings on these diseases taken under diverse conditions and at different stages of growth would be subject to considerable error. For example, the medium plus mosaic plants on July 18 and 22 did not show as serious symptoms as the mild mosaic plants on July 26 and August 4.

In comparing these symptoms with those of the corresponding plants in Plot B, it was found that the symptoms thruout the season were not as serious as in Plot A. The mild mosaic plants of Plot B are described in Table 7 as an example of the differences occurring. If this table be compared with the corresponding Table 2 for Plot A, it will be seen that the same differences in regard to temperature effects were present, but that all symptoms were less severe than in Plot A. One of the differences in the external factors between these plots is shown in Table 6, representing the soil moisture as per cent of the soil moisture equivalent. It is evident that the plants in Plot B were grown under drier conditions, and this may have had some effect on the symptoms. While this was an irrigated plot, no irrigation was made until after August 15, *i. e.*, after the last mosaic readings, because of the abnormally wet weather. There were, however, other differences in the soil of these plots that may have contributed to the effect. Plot B was a medium silt loam, while Plot A was a light sandy loam. The temperatures were about the same, that is, the plots were located on the same farm. Whether or not the soil moisture was chiefly responsible for the differences in symptoms is not entirely clear. Soil moisture experiments are being conducted in the greenhouse under control conditions to obtain more information on this point.

Effect of Date of Planting on the Symptoms.—This test was made to determine the influence of the age of the plants on their reaction to environment, as shown by changes in the symptoms.

The 3 plots designated as E, F, and G were planted at 20-day intervals as follows: Plot E on May 10, F on June 1, and G on June 20. All plots were in the same field.

As in previous experiments, the mild mosaic units were more influenced by environmental conditions than were the other units and will be used for an example.

Three readings were made, on July 6, July 18, and August 20. The temperature record of these plots is shown in figure 1. The mild mosaic readings are listed in Table 8. In this table the readings for the mild mosaic plants in Plot D are also listed.

Reference to the temperature record for these plots in figure 1 will show a distinct correlation between the rise in temperature and the disappearance of the symptoms. The mean weekly

TABLE 8. *Symptoms on mild mosaic plants, as related to date of planting*[1]

Date	Days after planting	Dwarfing	Chlorosis	Mottling	Wrinkling	Ruffling	Rugosity	Curling	Rolling	Uprightness	Rigidity	Brittleness	Spotting	Streaking	Burning	Leaf dropping
PLOT E PLANTED MAY 10																
July 6	57	...	...	2	1	2	2	3	2	...	...	...	...	...	.	
July 18	69	...	...	1	1	1	...	1	...	...	...	...	...	...	...	....
PLOT F PLANTED JUNE 1																
July 6	36	..		1	1	1	1	1			. .	...	.		.	
July 18	48	...	...	...	...	...	...	...	...	...	...	...	...	...	...	....
Aug. 20	81	. .		2	3	3	5	. .	5	..	. .	..				
PLOT G PLANTED JUNE 20																
July 18	28	. .		. .	...	...	...	...	...	. .	...	.	.		.	
Aug. 20	61		...	1	1	3	3	1	1	.		...	.			
PLOT D PLANTED JUNE 1																
July 3	33	...	...	1	2	...	2	1	.	.	.			.	.	
July 26	56	..	...	2	3	1	3	...	3	..	...	...	...	...	...	....
Aug. 24	85	.		2	3	2	2	2	5			..	.			..

[1]For explanation of symbols see Table 2.

temperatures had been low during the early growth of the plants in Plot E and even tho the mean temperature rose to 73° F. during the week ending July 6, the symptoms were still plainly evident. On the younger plants in Plot F, the symptoms on this date were much slighter, the high temperatures of the preceding week apparently having had a greater effect here than on the older plants in Plot E. The plants in Plot G were not up at this time.

During the period between the first reading on July 6 and the second reading on July 18, the temperature increased and the result was evidenced by the disappearance of the symptoms

on the plants in Plot F. The older plants in Plot E showed symptoms that were slighter, but that still were as evident as those in Plot F at the previous reading. No symptoms were present on the young plants in Plot G.

The period from the second to the third readings, July 18 to August 20, showed a marked decrease in temperature, and its effect was made evident by the reappearance of the symptoms in Plot F in a severe form, and by the first appearance of symptoms of the disease in Plot G. The plants in Plot E were mature at this time.

It is again evident that the older the plant is the slighter will be the effect of weather conditions that are unfavorable for the appearance of disease symptoms, while in a young plant the symptoms either will fail to appear or may disappear during hot weather only to appear later during a period of lower temperature. It may also be noted that the late planting in Plot G did not show symptoms until very late in the season, so that diseased hills in commercial fields planted late and growing under such weather conditions as were present here, might easily be missed if inspections were made early in the season. In the same way, if inspections were made during periods of hot weather, the disease in young plants such as those in Plot F would not be detected.

The other mosaic units showed somewhat similar reactions, but some symptoms were present at all readings. Apparently the more severe diseases or combinations of diseases were less influenced by the environment, as was found in Plot A.

Considering all the units in general in Plots E, F, and G, it may be said that the mosaic symptoms were more severe in the earlier plantings while the reverse was true of the spindle-tuber symptoms.

The plants listed in Plot D, grown from the same units as those in the other plots, showed more distinct symptoms on the mild mosaic units thruout the season. A glance at the temperature record in figure 1 will show that the temperatures were always lower than at the other plots listed. The seed was planted at about the same time as in Plot F, and the readings were made at approximately the same dates. The absence of the symptoms on the mild mosaic plants at the second reading in Plot F and their distinctness in Plot D, are especially significant in regard to temperature.

Effect on Yield.—While the previous experiment was not conducted in an effort to determine the effects of disease on yields, the difference in yield of the different disease types was

TABLE 9.—*Average yields in grams per plant from diseased types from all plots. 1923 experiments*

	Number of plants	Total weight	Marketable
		Grams	*Grams*
Mild mosaic	47	435	336
Medium plus mosaic	24	264	197
Mild mosaic + spindle-tuber	39	189	112
Spindle-tuber	25	173	63
Curly dwarf	25	86	20

so evident that the data were collected. In Table 9 are shown the average yields per plant. This is made up from all of the 6 plots previously listed. The number of plants was so small and the experimental error would be so great that no attempt was made to compare yields of the various plots. The averages here presented are fairly representative. The mild mosaic units in every case gave the greatest yield. The medium plus mosaic and the mild mosaic+spindle-tuber units varied in the different plots and gave about the same yield, being considerably less than the mild mosaic. Spindle-tuber alone reduced the yields in every plot to a point approaching that of curly dwarf. Practically 100 per cent of the tubers produced by the mild mosaic+spindle-tuber plants and by spindle-tuber alone were of the very severe elongated type with numerous shallow eyes characteristic of tubers affected with spindle-tuber, while curly dwarf plants produced 40 per cent of this type of tubers, indicating the presence of spindle-tuber in this symptom complex. Medium plus mosaic evidently has its spindle-tuber characteristics masked to a great extent by the rugose mosaic present in its complex because, of the tubers produced, only 2 per cent showed characteristic spindle-tuber symptoms.

No control plants are listed, as the rows grown for controls showed enough serious mosaic to reduce the yields slightly below those of the mild mosaic units.

FIELD EXPERIMENTS WITH MISCELLANEOUS MOSAIC

In 1921 a few preliminary experiments were started to study the effect of environment on the symptoms and yields of mosaic seed.

Methods.—A number of tuber units of Bliss Triumph mosaic seed and also a number of units of rogued Bliss Triumph were obtained from Maine.[1] Another lot of seed containing a high percentage of mosaic was obtained from Minnesota. Control rows were planted with certified Bliss Triumphs from Nebraska.

The seed was divided by cutting the potatoes in 3 pieces and planting at 3 different locations, as follows:

Plot 1—Planted April 20 at Lincoln, Nebraska.

Plot 2—Planted May 20 at the Substation at Mitchell, Nebraska, dry land culture.

Plot 3—Planted May 20 at the Substation at Mitchell, Nebraska, irrigated.

TABLE 10.—*Mean weekly air temperature for comparative weeks for plots 1, 2, and 3, 1921*

Comparative weeks[1]

	1	2	3	4	5	6	7	8	9	10
Plot 1.....	57	57	81	76	69	79	79	78	80	79
Plots 2 and 3..	73	69	79	69	78	79	76	71	73	73

[1]Plot 1—Temperatures for May 4 to July 13 inclusive.
Plots 2 and 3—Temperatures for June 10 to August 19 inclusive.

Table 10 shows the mean weekly air temperature at the 3 plots during the experiment. Further details regarding these plots have been previously described, Goss (1923). No aphids were observed in any of these plots during the season.

Results.—Table 11 gives the data on the percentage of disease present and on the yields resulting from these tests. The mosaic readings were based chiefly on the leaf symptoms. The mosaic plants in all plots showed a slight dwarfing so that the rows were distinguishable. No attempt was made to examine each individual plant any more closely than would be done in certification work. In general, the Maine mosaic seed showed the greatest amount of disease and produced the lowest yield in all plots. The Maine

[1]Seed obtained from Dr. E. S. Schultz, U. S. Dept. of Agriculture.

TABLE 11.—*Disease percentages and yields for 1921 experiments*

	Number of seed	Per cent germination	Per cent of disease			Total yield in grams per plant	Total yield per plant based on checks as 100 per cent
			Distinct mosaic	Mild mosaic	No symptoms		
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Grams*	*Per cent*
PLOT 1							
Checks	217	97.6	7.0	9.4	83.4	187	100
Maine rogued	61	98.3	20.4	50.0	29.5	170	90
Maine mosaic	46	95.6	40.0	48.3	11.6	77	41
Minnesota mosaic	235	96.1	28.7	35.3	35.8	143	76
PLOT 2							
Checks	220	61.8	.....	.....	.....	374	100
Maine rogued	94	42.5	25.0	27.5	47.5	336	89
Maine mosaic	48	50.0	8.3	62.5	29.1	189	50
Minnesota mosaic	205	73.1	16.0	26.0	58.0	247	66
PLOT 3							
Checks	219	65.7	.....	.....	.....	973	100
Maine rogued	94	73.4	5.7	5.7	88.4	669	68
Maine mosaic	48	81.2	5.1	15.3	79.4	562	57
Minnesota mosaic	211	83.8	4.5	8.4	87.0	818	84

rogued seed ran about the same as the Minnesota mosaic seed, while the controls showed the lowest amount of disease and the highest yields.

When comparing the different plots it is evident that the greatest amount of disease appeared in Plot 1, with Plots 2 and 3 following in the order of decreasing amounts. When it is considered that all of these plots were planted with seed from the same mother tubers it can be seen that there was a very great difference in the appearance of the disease in the different plots, the masking being very great in Plot 3, and that these differences can be explained by a comparison of the temperatures shown in Table 10. The mosaic readings in Plot 1 were made on May 20, that is, at about the end of the second week shown in Table 10, and it will be seen that the mean temperature averaged very low, below 60° F., for this period. In Plots 2 and 3 the readings were made August 16, that is, during the tenth week as shown in Table 10, and it can be seen that the tempera-

ture averaged above 70° F. at this time and during the preceding weeks. The difference in the amount of disease between Plots 2 and 3 is not so easily explained because the temperatures were practically the same. Plot 3 was irrigated and the soil moisture during most of the experiment was higher than in Plot 2, but nevertheless the amount of mosaic symptoms appearing during the experiment was very small. The soil in Plot 3 was more fertile and the plants made a much more rapid and vigorous growth, as evidenced by the yields.

It might be noted here that the conditions in Plot 1, where the greatest amount of disease was observable and where the lowest yields were obtained, were very similar to conditions prevailing in the southern potato states as will be pointed out later. A very low mean temperature and high soil moisture during the early growth of the plant favored the development of mosaic symptoms, and a very high temperature during the later part of the season was unfavorable for normal tuber development.

It is clearly evident from these results that the time of making an examination in the field and the conditions under which the plants are growing must be considered if accurate percentage readings of mosaic are to be made.

In 1922 a composite sample of the Maine mosaic seed from all three 1921 plots, comprising 330 plants, was planted at Lincoln on May 5. It might be expected that a considerable increase in the amount of mosaic would occur. Nevertheless several readings made during June and July showed only 5.6 per cent of distinct mosaic. There was some dwarfing and curling of leaves of all plants, but this was also present on the plants in the control rows planted with certified seed. The healthy rows could not be distinguished from the mosaic. The abnormal appearance of the leaves as well as the low percentage of mosaic can probably be explained by an examination of the temperature records for this year. The mean temperature during June and July when the mosaic readings were made was 75° F. for each month, and the soil moisture was considerably lower than in 1921. The germination and yield both total and marketable were as high for the mosaic rows as for the checks.

In 1923, seed from the 1922 plot was divided by cutting tubers into a number of pieces and by dividing the tubers from the same hills so that corresponding seed pieces from the same hill were obtained. These were planted in the 7 different plots described on page 15. Mosaic readings were made at least 3 times during the season. The results tabulated in Table 12 are made up from the total symptoms, that is, if a plant showed distinct mosaic at any time during the season, it was listed

TABLE 12.—*Disease percentages from miscellaneous mosaic experiments, 1923*

	Number of seed	Per cent germination	Per cent of disease		
			Distinct mosaic	Mild mosaic	No symptoms
		Per cent	*Per cent*	*Per cent*	*Per cent*
Plot A	112	93	26.6	49.5	17.1
Plot B	131	96	8.6	41.7	49.6
Plot C	131	99	6.9	53.8	39.2
Plot D	162	81	25.7	46.9	27.2
Plot E	52	100	17.2	53.8	28.8
Plot F	157	92	11.6	46.5	39.7
Plot G	147	93	7.9	11.5	80.4

under that heading. The increase in the amount of distinct mosaic in Plot A over Plots B and C was again evident. The conditions influencing this have already been discussed on page 23. Plot D as in the previous experiment showed a large amount of mosaic. The most noticeable difference, however, occurred in Plots E, F, and G. These, as already noted, were planted in the same field at intervals of 20 days. It was noticeable that the first planting in Plot E showed by far the greatest amount of mosaic, and that there was a considerable decrease in the next planting, Plot F, while in the last planting, in Plot G, 80 per cent of the vines appeared healthy.

It must be remembered that these different percentages of mosaic were found on plants obtained from the same seed and that this seed was from the 1922 experiments grown in turn from the plants listed in Table 9, originally obtained as mosaic units from Maine. It is again clearly evident that the differences obtained in the readings for mosaic were due to the conditions under which the plants were growing rather than to an increase in the actual amount of disease caused by transmission.

The yields of the various plots in Table 12 are not listed, as no clear-cut comparisons could be made. The plants listed as distinct mosaic did produce the lowest yield per hill, but the mild mosaic plants often outyielded the ones on which no mosaic symptoms appeared and sometimes yielded more than the control plants.

CORRELATION OF EXPERIMENTAL RESULTS WITH THE MOSAIC INCIDENCE IN COMMERCIAL FIELDS

The results obtained under control conditions and in the previous field experiments justify the question as to the effect of environmental conditions on the selection of seed potatoes being shipped to the South. While it has been generally observed that these diseases are much more serious in the South, no published data are at hand comparing the growing conditions of the South with those of the northern seed producing states. It has always been evident that seed sent South contained a higher percentage of degeneration diseases than was reported in the northern fields from which the seed was obtained. This was often attributed to aphid transmission late in the season in the North resulting in a higher percentage of disease in the progeny. The problem in Nebraska, that is, the increase of mosaic both in our northern plantings as well as in the plants grown in the South, could not be explained on this basis, inasmuch as aphids are very rare in the dry land sections of the West.

In 1920, 1921, and 1922, the author in many observations could not find more than an occasional aphid present in a very small number of the fields inspected. In 1923, the high rainfall was assumed to be more favorable for an infestation, and a close inspection of fields was made.

The author personally inspected about 2,000 acres of dry land potatoes and was unable to find more than a trace of aphids. A survey[1] was made of 18 fields in Scotts Bluff County, 10 of which were irrigated. Eight of the 10 irrigated fields contained aphids on 18 per cent of the plants. Seven of the 8 dry land fields in the same locality contained aphids on 4 per cent of the plants. In all cases, only one or two aphids were present on a plant.

Inasmuch as all seed now certified in Nebraska and most of the general seed crop are grown under dry land conditions, the small number of aphids present in what can be considered the most favorable year for an infestation, would hardly account for any considerable increase in the percentage of mosaic.

The following record obtained from the certification records of the Horticultural Department, Nebraska Agricultural College, and from reports from Mr. G. L. Tiebout and Dr. C. W. Edgerton of the Louisiana Agricultural Experiment Station, gives some idea of the amount of mosaic in northern grown seed potatoes when planted in the South.

[1]This survey was made by Mr. William Morrow, Field Assistant.

The average of mosaic in 4 strains grown in Nebraska in 1921 was 0.4 per cent. These 4 strains tested in Louisiana in 1922 showed 16.0 per cent mosaic. The same seed grown by the same growers in commercial fields of Nebraska in 1922 showed 1.0 per cent mosaic. In the 1923 tests in Louisiana, 11.1 per cent mosaic was reported, while in 1923 the records in Nebraska showed 6.0 per cent mosaic. These differences between Louisiana and Nebraska percentages in the same stock, can be explained by the effect of different environmental conditions on the symptoms of the disease.

A certain number of strains of Bliss Triumphs grown in Nebraska in 1922 were planted at Baton Rouge, Louisiana, and mosaic readings were made by Mr. H. O. Werner of the Horticultural Department of the Nebraska College of Agriculture, on April 23, 24, 1923. The following table shows the average percentage of mosaic per field in the commercial fields in Nebraska in 1922, in the Louisiana tests in 1923, and in the commercial fields grown from the same seed in Nebraska in 1923:

Number of strains	Nebraska 1922 *Per cent*	Louisiana test 1923 *Per cent*	Nebraska 1923 *Per cent*
40	1.0	5.8	4.0
32	1.5	16.9	....

Some of the lots tested in Louisiana showed enough mosaic to discourage their planting again in Nebraska and these fields were listed separately. These tests show not only the effect of climatic conditions on the visibility of mosaic symptoms, but also the use to which such a test can be put in eliminating undesirable lots. It must also be noted that the Louisiana readings include all plants grown in the test plots while the readings in the commercial fields of Nebraska would be influenced by roguing. In 1922 most of the roguing was done after the mosaic readings were made so that the visible mosaic in the strains planted in both Louisiana and Nebraska in 1923 had been removed. In 1923 a considerable amount of mosaic had been removed from the fields before the mosaic readings were made. These facts would tend to increase the differences shown in the above table.

Considering now the conditions under which these crops were grown, we find a marked correlation between the weather conditions and the amount of visible mosaic.

In figure 2 the mean weekly temperatures for comparative weeks of different potato sections of the country are plotted. For this purpose a 2-month period was taken covering the time from the emergence of the plant to the time the foliage is fully developed. These periods may not be exactly comparable, but

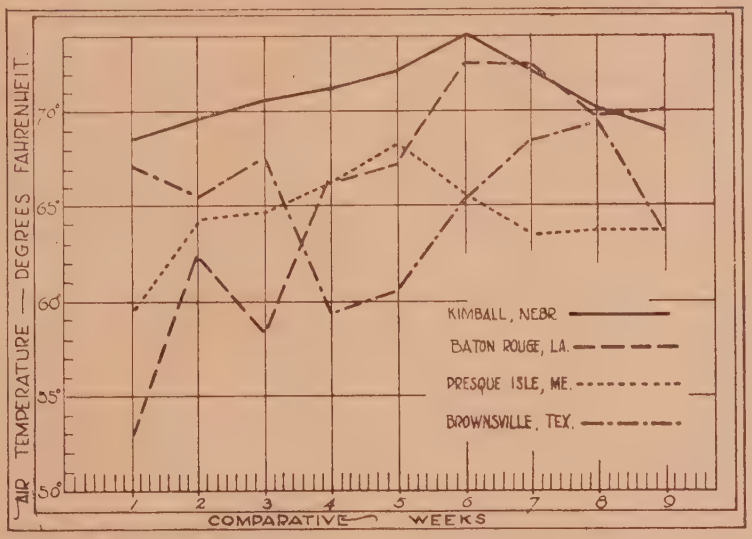

FIG. 2.—Graph showing weekly mean temperatures for comparative weeks of different potato growing sections.

Kimball, Nebraska, June 15 to August 15, six-year average.

Presque Isle, Maine, June 15 to August 15, ten-year average.

Baton Rouge, Louisiana, March 15 to May 15, 1923.

Brownsville, Texas, January 15 to March 15, 1923.

The normal temperatures by months for Baton Rouge and Brownsville are shown in Table 13.

they are close approximations made by a number of observers in the several localities. Mosaic readings are made in Nebraska chiefly in July, while in Louisiana the disease usually appears very marked in April. While the 2-month period shown in figure 2 may extend over a greater length of time than that usually used for the detection of mosaic it is believed to cover the period during which mosaic symptoms would be greatly influenced by external conditions. Further monthly data are presented in Table 13, covering a 3-month period and comparing the 1923 data for Brownsville and Louisiana, from which figure 2 is composed, with the normal monthly mean for those localities.

It can be easily seen that Kimball, Nebraska, temperatures are consistently higher than the others and for 6 weeks are above 70° F. It is also true that these diseases are usually severe at the 2 southern points and in Maine and this can be directly correlated with the lower temperatures occurring in those localities.

TABLE 13.—*Normal monthly mean temperature, precipitation, and sunshine for comparative months in different potato sections*[1]

Comparative months	June July August		March April May		Jan. Feb. March		June July August	
	Kimball, Nebr.		Baton Rouge, La.		Brownsville, Tex.		Presque Isle, Me.	
	TEMPERATURE °F.							
	Normal	*1923*	*Normal*	*1923*	*Normal*	*1923*	*Normal*	*1923*
1.....	65.3	64.2	61.0	58.6	48.4	56.4	59.8	59.2
2.....	71.1	72.6	66.9	67.9	50.3	49.1	66.1	62.4
3.....	69.7	67.6	73.8	72.5	68.4	65.0	63.1	58.8
	PRECIPITATION							
1.....	2.3	4.7	4.51	6.3	1.75	1.8	3.9	0.8
2.....	2.3	2.4	4.72	6.2	1.80	4.5	3.3	4.3
3.....	1.7	3.5	4.33	8.0	1.23	1.3	3.2	2.3
	DAYS CLEAR (AND PARTLY CLOUDY)							
1	17 (10)	13 (13)	.....	12 (7)	.....	17 (6)	14 (10)	21 (6)
2.....	13 (16)	10 (20)	.....	12 (8)	.....	7 (5)	16 (8)	16 (6)
3	15 (14)	12 (16)	.....	13 (13)	.....	8 (15)	16 (9)	15 (11)

[1]Normal temperatures and precipitations for Kimball, Baton Rouge, and Brownsville are calculated from the departures from normal given by the U. S. Weather Bureau Monthly Records for 1923. Normal and clear days for Kimball were compiled from 6-year records. The data for Maine were obtained thru the courtesy of Dr. Folsom of the Maine Agric. Expt. Station. These data are from 8 to 10 year records in every instance.

The usual assumption that southern potatoes do not make good seed because of the high temperatures at which they are grown would apply, in the early crop at least, only to the period during which tuber formation takes place. At both Brownsville and Baton Rouge the temperature increases rapidly during the later stage of growth, while it decreases in Maine and Nebraska; this would be even more evident if the last month of the potato season were shown.

If we compare the temperatures for the months in the various sections during which mosaic determinations are usually made, *i. e.*, from the third to the sixth week inclusive as shown in figure 2, it will be seen that there is considerable difference in the temperatures. It is also evident from Table 13 that no clear cut correlation can be made between mosaic and rainfall or even sunshine. Rainfall, however, is here considered only for the stated period of growth, and can often be correlated with lower temperatures and decreased sunlight. If the precipitation records of the months preceding planting were considered, it would influence the amount of moisture in the soil. This would necessitate a comparison of the different soil types and cannot

be undertaken here. It is clearly evident, however, that low temperatures are necessary for the appearance of mosaic symptoms and that the mean temperatures in the southern states and in Maine are much lower than for the corresponding periods of growth in Nebraska. The point used to represent temperature conditions in Nebraska, *i. e.*, Kimball, has even a lower mean temperature than other seed potato producing sections of western Nebraska.

A complete study of the problem, however, must also take into consideration the effect of these factors on plant growth. It is true that the number of clear days is not greatly different in these different sections, as shown in Table 13. If we would consider the intensity of sunlight, however, it would be found that the Nebraska fields are subjected at their high altitude to a very intense sunlight which usually causes all the leaves to droop in midday and this factor in combination with high temperatures usually decreases the visibility of mosaic symptoms.

The records here shown explain very well the differences in the readings of mosaic in Nebraska and Louisiana as previously noted. The correlation shown for widely different locations can also be made for different seasons in the same region. The difference in the amount of mosaic present in the commercial fields in Kimball County, Nebraska, in 1922 and 1923 was considerable as is shown by the following table:

Year	No. of fields	Total acreage	Average percentage of mosaic per field
1922	44	607	0.6
1923	75	1333	3.0

About 70 per cent of the fields in 1923 were planted with seed from the 1922 crops. In 1922, no fields were rejected in this county on account of mosaic; while in 1923, 13 fields were rejected, and averaged 8.0 per cent mosaic.

In 1922 no aphids could be found and they were very scarce in 1923, so the increase of disease could hardly be attributed to aphid transmission.

If the weather conditions are considered, it is very plain that these results were not caused by aphid transmission, but that what probably occurred was a masking of the symptoms in 1922, thus preventing successful roguing and seed selection. An examination of figure 3 will show that the mean weekly temperatures for 1922 were above 70° F. for the greater part of the season. The temperatures were highest during the period when inspections are usually made in the fields. In 1923 the mean temperatures were consistently below 70° F. A comparison of

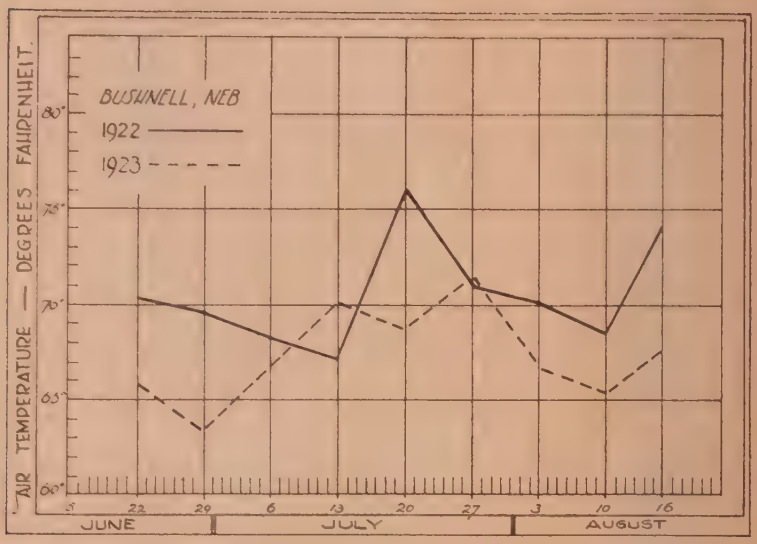

FIG. 3.—Graph showing weekly mean temperatures in Kimball County, Nebraska, for 1922 and 1923. Records taken at the farm of August Gadeken, Bushnell, Nebraska. Means obtained from 2-hour readings for each week.

rainfall and sunshine shows an increase in the precipitation for 1923 over that of 1922, and a considerable decrease in the number of clear days as tabulated below:

	June		July		August		Total	
	1923	1922	1923	1922	1923	1922	1923	1922
Clear days	13	22	10	15	12	18	35	55
Rainfall, *inches*	4.70	2.08	2.48	1.08	3.55	1.66	10.73	4.82

The same reaction evidently occurs in other sections as shown by the data in Table 14, obtained from Dr. Folsom of the Maine Agricultural Experiment Station on the relation of weather conditions to the appearance of mosaic symptoms at Presque Isle, Maine, for the comparative years of 1921 and 1923.

Folsom notes that 1921, the poorest year for the appearance of mosaic symptoms and in which symptoms did not appear in some plots known to have the disease, had low precipitation for May, June, and July and a high mean temperature for July, compared with the normal, (see Table 13). In 1923, the latest year both for growth of the plants and the appearance of mosaic symptoms, late planting was correlated with low temperature in

TABLE 14.—*Relation of weather to the appearance of mosaic symptoms at Presque Isle, Maine in* 1921 *and* 1923 [1]

	Mean temperature		Precipitation		Clear	Partly cloudy	Clear	Partly cloudy
	1921	1923	1921	1923	1921		1923	
	°F.	*°F.*	*In.*	*In.*	*No.*	*No.*	*No.*	*No.*
May	53.4	46.5	1.63	1.58	17	10	14	10
June	58.8	59.2	1.58	0.82	13	7	21	6
July	71.8	62.4	2.49	4.32	19	5	16	6
August	60.8	58.8	5.43	2.32	15	8	15	11
Sept	56.3	54.1	3.15	2.98	16	6	20	4

[1] 1921—Poor mosaic symptoms; 1923—good mosaic symptoms.

May and low precipitation in May and June. This, however, followed a winter of heavy snowfall and the ground was very wet in May. Good mosaic symptoms appeared in 1923 and were correlated with low temperatures in July and August.

DISCUSSION

It has been shown that under control conditions high temperatures (above 70° F.) seriously decrease the visibility of mosaic symptoms. The same effect has been observed in field experiments and in commercial fields. The mottling of mosaic leaves is decreased by high temperature and the addition of intense sunlight eliminates this symptom. High temperatures tend to produce a smoother leaf, thus masking the symptoms of wrinkling, curling, rolling, and rugosity. High soil moistures apparently favor the appearance of such leaf symptoms. It must be remembered, however, that under average field conditions in Nebraska, increased rainfall usually is accompanied by decreased temperatures and sunlight. When all 3 factors are controlled, temperature appears to have the greatest influence.

Field experiments have shown that a short period (4 to 8 days) of high temperature with intense sunlight, eliminates the symptoms of mild mosaic. The symptoms are more affected by environmental conditions during the early growth of the plant and the effect decreases with age. The more severe types of

mosaic do not react as rapidly or completely to external conditions as the milder types. The date of planting in the same locality resulted in a wide divergence in the amount of visible mosaic at any specified date.

Taking all these factors into consideration, it must be admitted that there will necessarily be a large error in field readings made without regard to these factors. To make an accurate estimate of the amount of mosaic in a field, it becomes necessary to consider the date of planting and the environmental conditions under which the plant has been growing, particularly with reference to the period immediately preceding the examination. Determination of mosaic should not be made on very young plants unless under the most favorable conditions, as the symptoms will be masked more rapidly than on slightly older plants. Roguing to be complete should be done only during periods when the appearance of the symptoms of the disease is favored by climatic conditions.

It has been shown that these results not only can explain to a large extent the variations in mosaic readings during any one year in a particular field, but also the changes occurring during several seasons in the same locality or even the apparent increase in mosaic occurring when "northern grown" seed from the western states is planted in the southern states.

The examples shown in the southern states, *i. e.*, Baton Rouge, Louisiana, and Brownsville, Texas, indicate that the temperatures prevailing there, as in Maine, are normally low enough during the early season to favor the appearance of mosaic symptoms. The reverse is true for Nebraska and probably a considerable area in the West. The low temperature in the South during the early period of growth is often followed by extremely high temperatures during the period of tuber formation, thus greatly decreasing their yields.

In Nebraska, there are indications that mild mosaic does not materially decrease the yield. However, accurate percentages of this type are difficult to obtain because of the rapid masking of symptoms. Combinations of this type of mosaic with spindle-tuber would occur in the fields and would reduce the yields materially. Therefore, there is no reason why this apparently less injurious type of disease should be allowed any greater tolerance in seed potatoes.

The reversing of certain types of the disease occurred when grown under different conditions. That is, under certain conditions, medium plus mosaic, or mild mosaic+spindle-tuber, appeared much less severe than mild mosaic grown under other con-

ditions that were more favorable for the appearance of the symptoms. This complicates the problem and makes it impossible to detect any particular disease type with certainty, under field conditions, even when insect transmission is eliminated.

While mosaic symptoms are more evident with early planting and lower temperatures, the reverse appears to be true for spindle-tuber. Spindle-tuber and combinations of spindle-tuber with mosaic result in a greater decrease in yield than mosaic alone.

In the opinion of the author, the effect of the high temperature, low rainfall, and intense sunlight in certain areas of the West is of as great importance as aphid transmission. They are often the chief factors responsible for the apparent increased amounts of mosaic in our seed stock, the masking of the symptoms preventing good results from roguing and seed selection; and of these factors temperature is the most important.

Further work is greatly needed in the West for the proper understanding of this problem, which in most of its aspects is considerably different from those in the eastern states. This is true regarding the environment, the varieties being grown, the number of aphids present and the possible presence of other insect carriers of the disease as well as the native plants which may be possible over-wintering hosts. The work reported in this publication is preliminary in nature and is being followed by further studies on the effect of temperature, moisture, and sunlight.

LITERATURE CITED

1. Ducomet, V.
1923. SUR LA VISIBILITE DES SYMPTOMES DE LA MOSAIQUE DE LA POMME DE TERRE. Rpt. Int. Conf. of Phytopathology & Ec. Ent. Holland. p. 39-43.

2. Goss, R. W.
1923. RELATION OF ENVIRONMENT AND OTHER FACTORS TO POTATO WILT CAUSED BY FUSARIUM OXYSPORUM. Neb. Agr. Exp. Sta. Res. Bul. 23, 84 p.

3. Johnson, James.
1922. THE RELATION OF AIR TEMPERATURE TO THE MOSAIC DISEASE OF POTATOES AND OTHER PLANTS. *In* Phytopathology v. 12, no. 9, p. 438-440, fig. 1.

4. Murphy, P. A.
1921, (A). INVESTIGATION OF POTATO DISEASES. Canada Expt. Farms. Div. Bot. Bul. 44, ser. 2, 86 p. 35 figs.

5. ———.
1921, (B). SOME RECENT WORK ON LEAF ROLL AND MOSAIC. *In* Roy. Hort. Soc. Rpt. Internat. Potato Conf. p. 145-152.

6. Peltier, George L.
1923. A STUDY OF THE ENVIRONMENTAL CONDITIONS INFLUENCING THE DEVELOPMENT OF STEM RUST IN THE ABSENCE OF AN ALTERNATE HOST. II. INFECTION STUDIES WITH PUCCINIA GRAMINIS TRITICI FORM III AND FORM IX. Nebr. Agr. Exp. Sta. Res. Bul. 25, 52 p. pls. 1-12.

7. Quanjer, H. M.
1921. NEW WORK ON LEAF-CURL AND ALLIED DISEASES IN HOLLAND. *In* Roy. Hort. Soc. Rpt. Internat. Potato Conf. p. 127-145.

8. ———.
1923. GENERAL REMARKS ON POTATO DISEASES OF THE CURL TYPE. Rpt. Internat. Conf. of Phytopathology and Econ. Entomology, Holland, p. 23-28, pls. 1-4.

9. Schultz, E. S., Folsom, Donald, et al.
1919. INVESTIGATIONS ON THE MOSAIC DISEASE OF THE IRISH POTATO. *In* Jour. of Agr. Res. v. 17, no. 6, p. 247-273, col. pl. A-B, pls. 25-30.

10. Schultz, E. S., & Folsom, Donald.
1920. TRANSMISSION OF THE MOSAIC DISEASE OF IRISH POTATOES. *In* Jour. Agr. Res. v. 19, no. 7, p. 315-337, pls. 49-56.

11. ———.
1921. LEAFROLL, NET-NECROSIS, AND SPINDLING-SPROUT OF THE IRISH POTATO. *In* Jour. Agr. Res. v. 21, no. 1, p. 47-80, pls. 1-12.

12. ———.
1923. TRANSMISSION, VARIATION, AND CONTROL OF CERTAIN DEGENERATION DISEASES OF IRISH POTATOES. *In* Jour. Agr. Res. v. 25, no. 2, p. 43-117, pls. 1-15.

(3M)

UNIVERSITY OF NEBRASKA PRESS